



Spatio-Temporal Dynamics of Nitrogen Dioxide (NO₂) Concentration & its Impacts on Human Health (2010-2022)

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Abstract.

Nitrogen is one of chemical gases which has drastic impact on human health. It is also renowned globally as a major component of climate change. Lahore city has been selected as the study area to conduct this research. The basic objective of this study is to assess the temporal and seasonal change of Nitrogen Dioxide (NO₂) concentration in the study area and its effects on human health. For this purpose, the two-phase methodology has been adopted. In the first phase, primary and secondary datasets were collected through an online questionnaire and Environmental Protection Agency (EPA), respectively, while in the second phase, satellite imageries were acquired from NASA Earth Observatory (NEO). An online questionnaire survey was conducted for a better understanding and assessment of NO₂ effects on inhabitants. The interpolation technique was applied to show a temporal change in Concentration of NO₂ from 2010-2022 and for seasonal change in 2022. Findings of this research showed that NO₂ levels are high during winters as compared to summers. Whereas, temporal analysis from 2010-2019 revealed that high dense columns of NO₂ were found in 2019 & 2020 and less dense columns were found in 2019, whereas this concentration declined due to the arrival of COVID from 2020 to the end of 2021. The main reason of this decline is the lack of transport or industrial exhaust due to lockdown by COVID. The results of the questionnaire indicate that people encountered diverse health problems due to long- and short-term exposure to NO₂. Moreover, this study helps to display the drastic impacts of NO₂ concentration on human health and the natural environment.

Keywords: Nitrogen Dioxide Concentration, Interpolation, Human Health, Climate Change

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Conflict Of Interest:

The author(s) declare that the publication of this article has no conflict of interest.

Introduction

Nitrogen dioxide is a major catalyst in tropospheric ozone. Nitrogen has various combinations, although NO₂ is considered toxic amongst all [1]–[3]. According to [4], [5] burning of fossil fuels significantly increases due to emissions of NO₂, which rose to 70%. The Spatio-temporal trends of NO₂ are required to evaluate immediately, which would help to overcome the existing and potential risks to human health [6], [7]. According to [8], emission of pollutants is recorded higher during working days in comparison to holidays due to intercity mobility. As per references, [9], [10] stated that Nitrogen Dioxide has a limited lifecycle. Due to air pollution, about 3.7 million deaths have been reported per year. To measure the Concentration of CO, NO₂, and O₃ various techniques have been used [11], [12]. As per reference, [13][14] the author identified that industrial and traffic activities are major sources of air pollution[15].

Nitrogen dioxide has been produced by anthropogenic activities in Pakistan, which has boosted the adverse effects on the environment more than in other countries[16]. These impacts are caused by the burning of fossil fuels, poor management of rapid industrialization, motor combustion, and an increased number of poorly maintained vehicles [17]. As per reference [18][19], the author demonstrated that major cities of Pakistan have recorded high levels of NO₂ in the winter season and lower in summer [20]. However, the high peak in population and industrialization are notable factors that have increased the Concentration of NO₂[21][22].

Evaluation and assessment of air quality and numerous pollutants are required to understand the coarse effects of these sources in Pakistan. Various root causes e.g., stationary and non-stationary sources of pollution, are significantly influencing the environment and human health. A degraded observation system is one of its factors; therefore, an advanced systematic and holistic approach is required to be adopted. This study will help to identify the key factors which are significant in detecting the Concentration of NO₂ in Lahore city.

Study Area

This study was conducted in Lahore (Figure 1). It has a rapid escalation of environmental pollution. In addition, population growth and economic activities have participated adversely. Citizens have choices to own multiple vehicles of every type; it causes a substantial growth in vehicle numbers that leads to the high concentrations of pollutants in the city. Especially, it directly affects air pollution due to enormous emissions, and a high concentration of NO₂ is one of them [21], [23]–[25].

Materials and Methods

To conduct this research, both primary and secondary data were collected. A Questionnaire, based survey was conducted through online mode (Figure 2). A set of 22 questions was prepared on survey planet, and the link was shared with environmentalists via emails on different platforms. The total number of respondents was 100-109 from diverse locations in Lahore. The questionnaire methodology was adopted as per reference to observe the effect of nitrogen dioxide concentration on human health. The main purpose of the questionnaire was to get an idea of how people perceive air pollution and its effects on human health and to know the spatial location where health affects more or less due to ambient air quality. The real-time variation in NO₂ Concentration was collected from the Environmental Protection Agency (EPA), Lahore. To determine spatiotemporal variation in NO₂, data was collected of AIRS sensor for the time period (2010-2022) from GIOVANNI. To show the changes in Concentration of NO₂, interpolation technique was applied in ArcGIS 10.5.

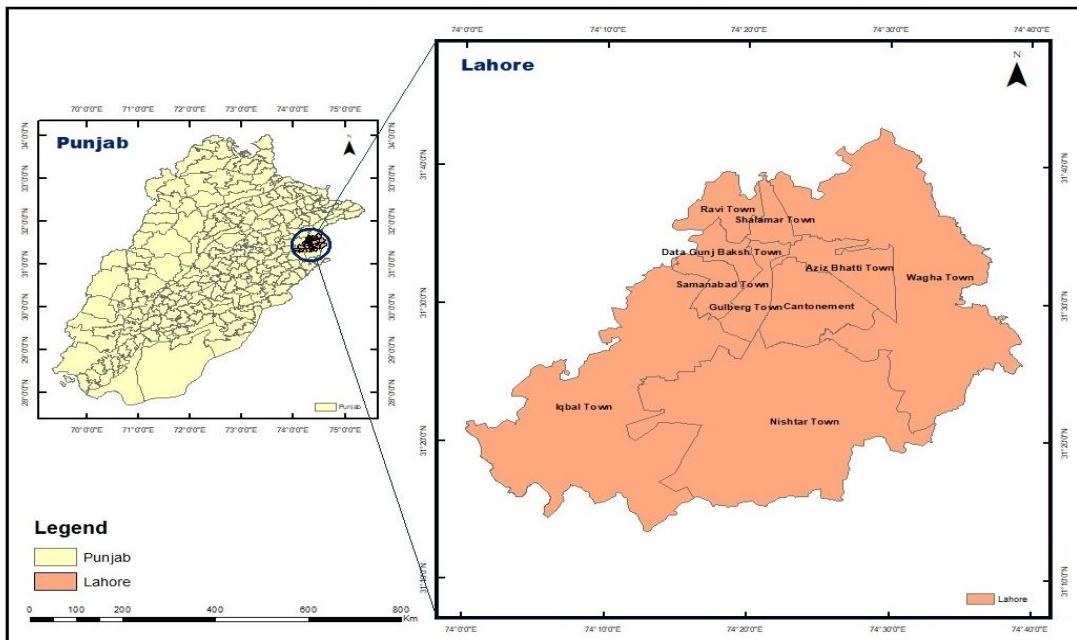


Figure 1. Study Area

Results and Discussion

Temporal Changes in Concentration of Nitrogen Dioxide

The NO₂ concentration as measured by satellite imageries was used to determine the temporal changes over the study site. It shows that this concentration has increased in comparison to the year 2010, which has minimal values of less than 50 µg/m³ and maximum values of 100-150 µg/m³.

The highest value of NO₂ was recorded in 2015, which raised to 150-200 µg/m³ in the northeast and northwest, except in the southeastern part of the city, including areas in Nishtar town and some areas of Iqbal town 50-100 µg/m³. While medium levels are shown in the southwest of the city, which is 100-150 µg/m³ (Figure 3). Comparatively, the results of 2019 show a maximum NO₂ concentration of more than 250 µg/m³. More specifically, Shahdara town, Samanabad, Gulshan Ravi, and some parts of Iqbal town on the northwestern side are vulnerable to the maximum concentrations. While less Concentration of NO₂ from 50 to 150 µg/m³ is visible in Cantonment, Gulberg, Aziz Bhatti Town, Nishtar Town, and south of Iqbal town. The overall results and comparison of these three years have defined the enormous change in concentration of NO₂ in the city caused by traffic, usage of fossil fuels for domestic purposes, and various agro-industrial activities. In addition, the frequent climatic scenarios affect the air quality of the city, and it has been poorly worsened due to the high peaks of multiple pollutants from 2010 to 2019.

Seasonal Changes in Concentration of NO₂

It has been analyzed in the study that the Concentration of NO₂ varies during summer and winter. Furthermore, several climatic factors like wind, temperature, and rainfall patterns affect the concentration levels of pollutants, including NO₂. Figure 4 describes four months, January, March, July, and October, according to the seasonal patterns in Lahore.

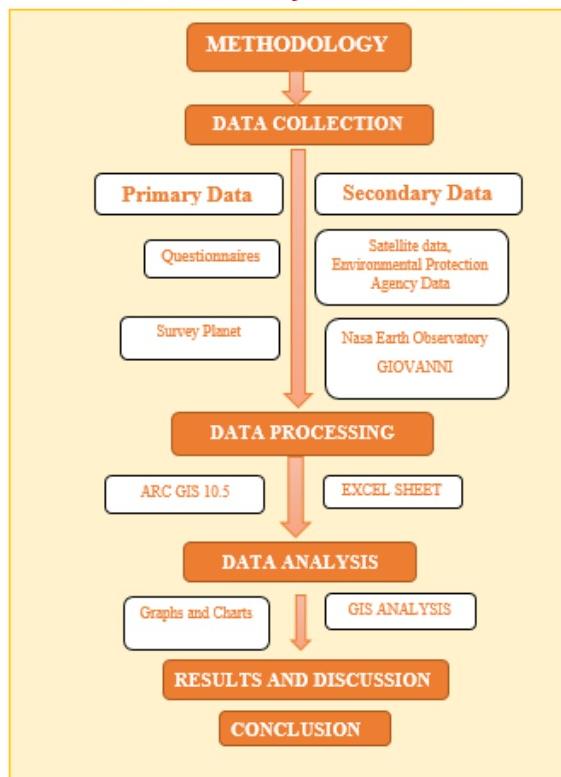


Figure 2. Step by step flow of methodology

In the peak winter, during the month of January, the Concentration of NO₂ was observed to be highest in the whole month above 250 µg/m³ because the pollutants remain dense due to cold wind for a long time that causing to increase in the Concentration of NO₂, resulting in low visibility and breathing problems. In comparison, March is considered a relatively moderate temperature with a less rainfall ratio. In 2019, the Concentration in March was recorded as moderate, between 50 to 200 µg/m³. There was a minute variation in the patterns of concentration, except the levels decreased in comparison to winter.

During July, most of the city was covered with high concentrations of NO₂ ranging from 50 to more than 250 µg/m³ due to the effect of the highest rate of rainfall and humid air, which caused the pollutants to get stable in the air. During October, NO₂ concentration levels were recorded higher in the southern part of the study site. The seasonal changes were recorded by satellite sensors which were later interpolated to examine the spatial trends.

The Concentration of Nitrogen Dioxide in Lahore on Monthly Basis

The Environmental Protection Department shared the levels of NO₂ in Lahore city. The average Concentration of NO₂ is shown in Figure 5. Various levels of NO₂ are showing fluctuation within a month which is due to the rainfall and wind pattern. Therefore, the average levels of NO₂ in January and February which were 97.44 and 68.23 µg/respectively.

Whereas, the highest concentration was observed in July i.e. 113.5 µg/m³. Hence it is proved that the humidity also disturbs the overall concentration in the atmosphere. It is obvious that after July the NO₂ columns fluctuate visibly i.e. 67.7 µg/m³ in August then it remains around 70 to 80 µg/m³ till October. After this month the NO₂ columns greatly increased and recorded about 100-110 µg/m³. It must be noticed that when these conditions are combined with anthropogenic activities, it creates a disastrous situation for Lahore city that affects the air quality of the city but also has adverse effects on the health of residents.

The data clearly shows a higher value of NO₂ concentration than the international standards, which is 10 µg/m³ annual mean and 24 µg/m³ of a complete day.

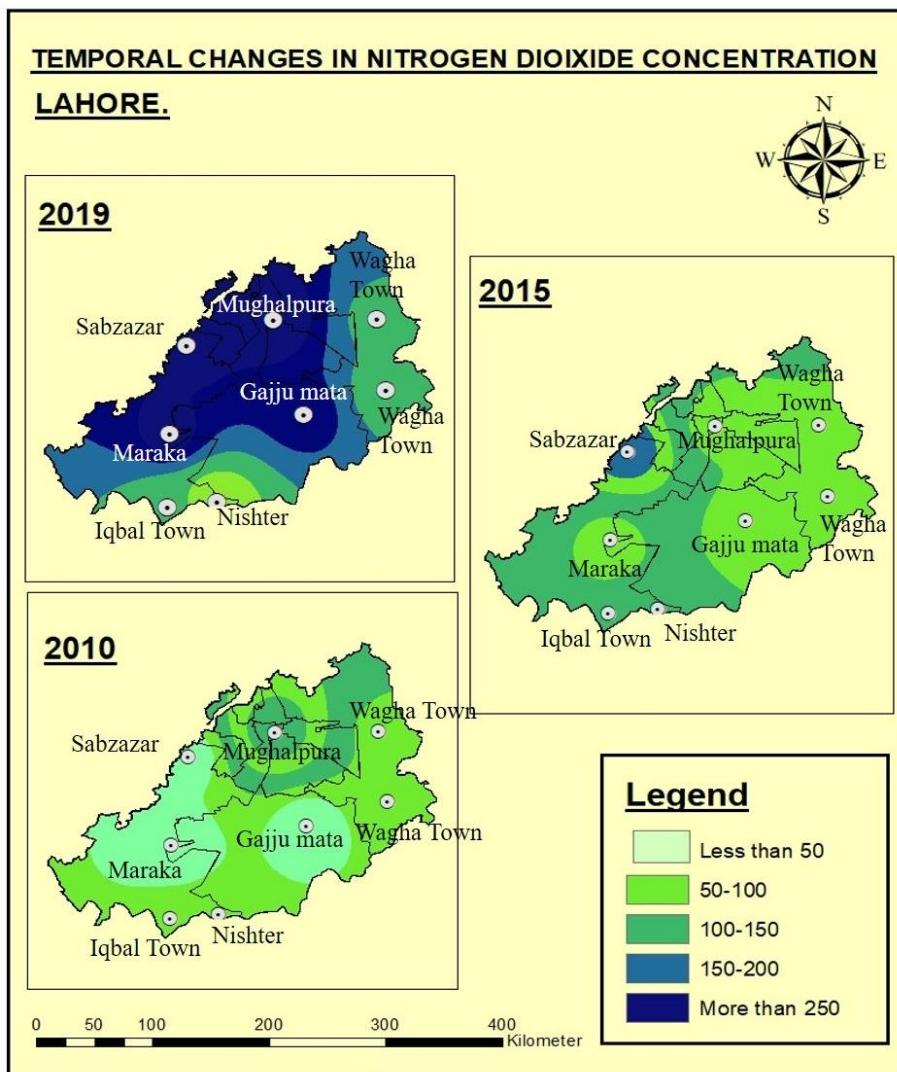


Figure 3. Map showing Ten years' concentration fluctuations in NO₂

On the other hand, Figure 6 clearly shows the weather condition during December 2019. It indicates how the city is covered with thick clouds throughout the month, which causes the air particles to become denser, resulting in a rise in NO₂ levels. A thick concentration of smog was also noticed. When these conditions are combined with the industrial and traffic activities in Lahore city, make the air quality worsens, causing major health issues among the people of Lahore.

Impact of NO₂ Concentration on Human Health

The air quality affects human health and the environment. The long-term exposures to harmful air quality having high levels of NO₂, CO, and particulate matter cause severe health problems for people. While in the short term, people can have irritations, allergy to eyes, dry throat, sneezing, or runny nose. Lahore is amongst one of the most air polluted cities around the world due to its climatic condition- smog and anthropogenic activities.

The questionnaire data were utilized to assess the impact of Nitrogen dioxide on human health. Figure 7 shows various health issues for example eye irritation, cough, sneezing, sleep disorder etc. faced by residents in various towns of city. It shows that the people residing

in the northern areas of the city have experienced short and long-term health effects according to the low temperatures and cold season caused probability of higher concentrations in the northern exposure of higher concentrations of NO₂. The densely populated and bottleneck areas of Lahore are mostly exposed to the higher concentration levels of NO₂.

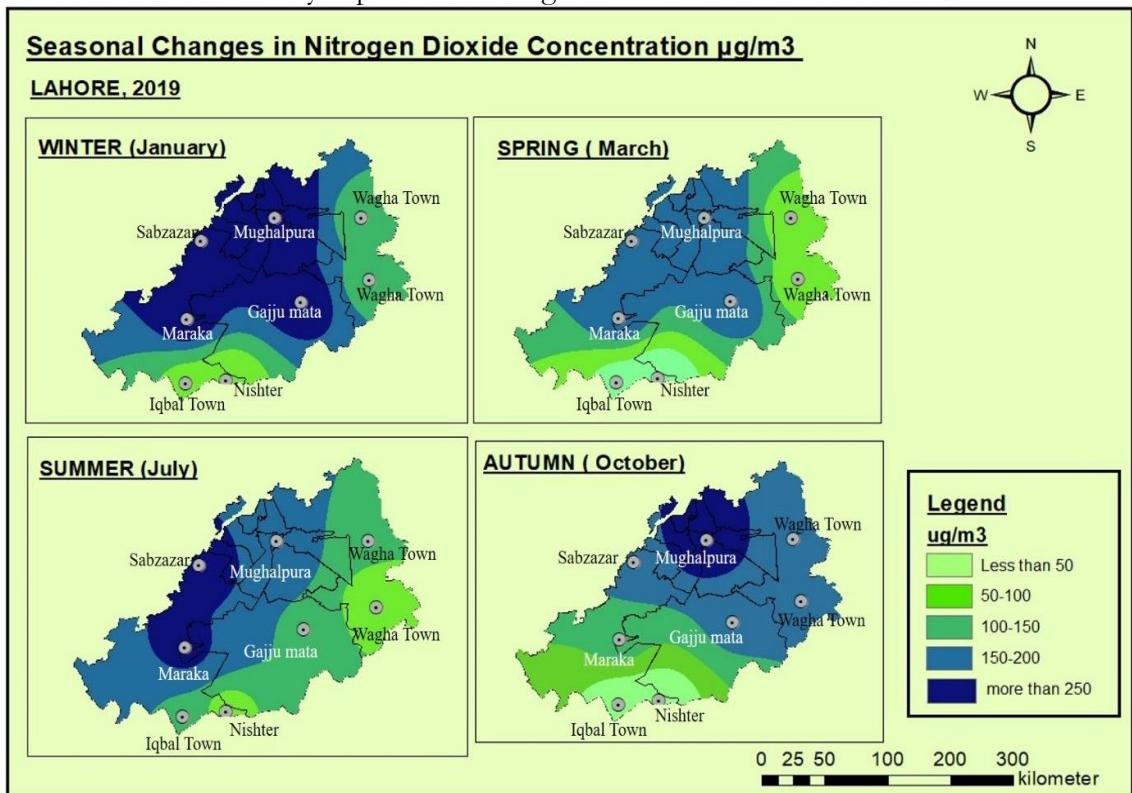


Figure 4. Map showing seasonal changes in columns of NO₂ 2019

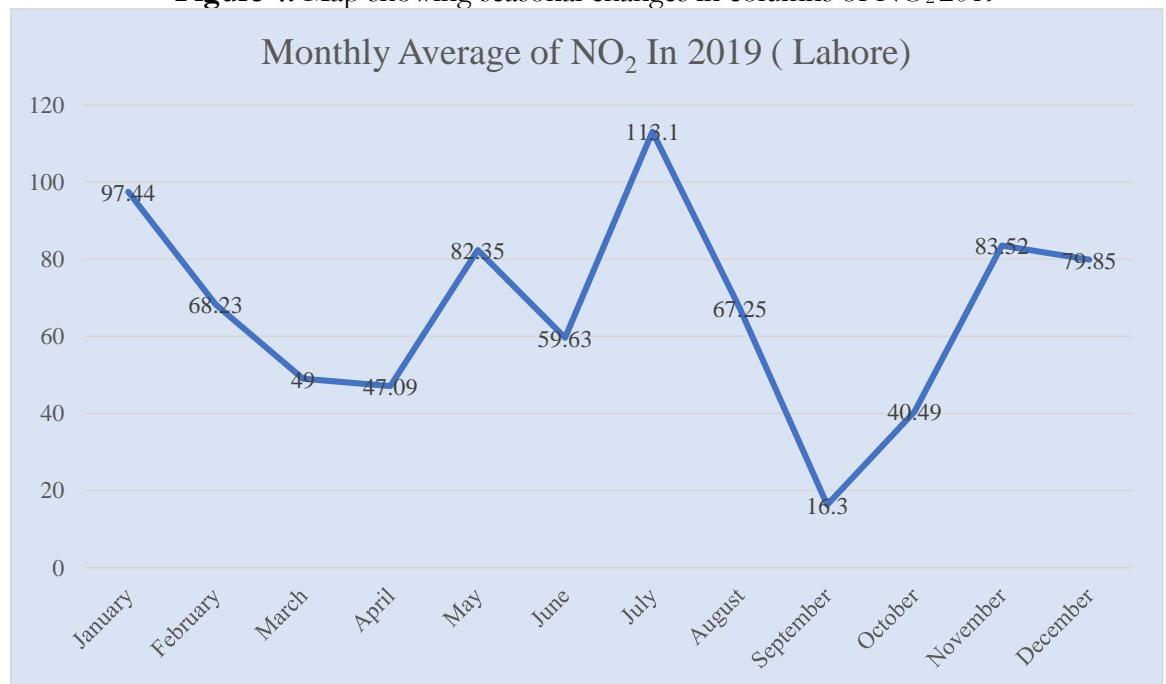


Figure 5. Monthly average of NO₂ Concentration in Lahore

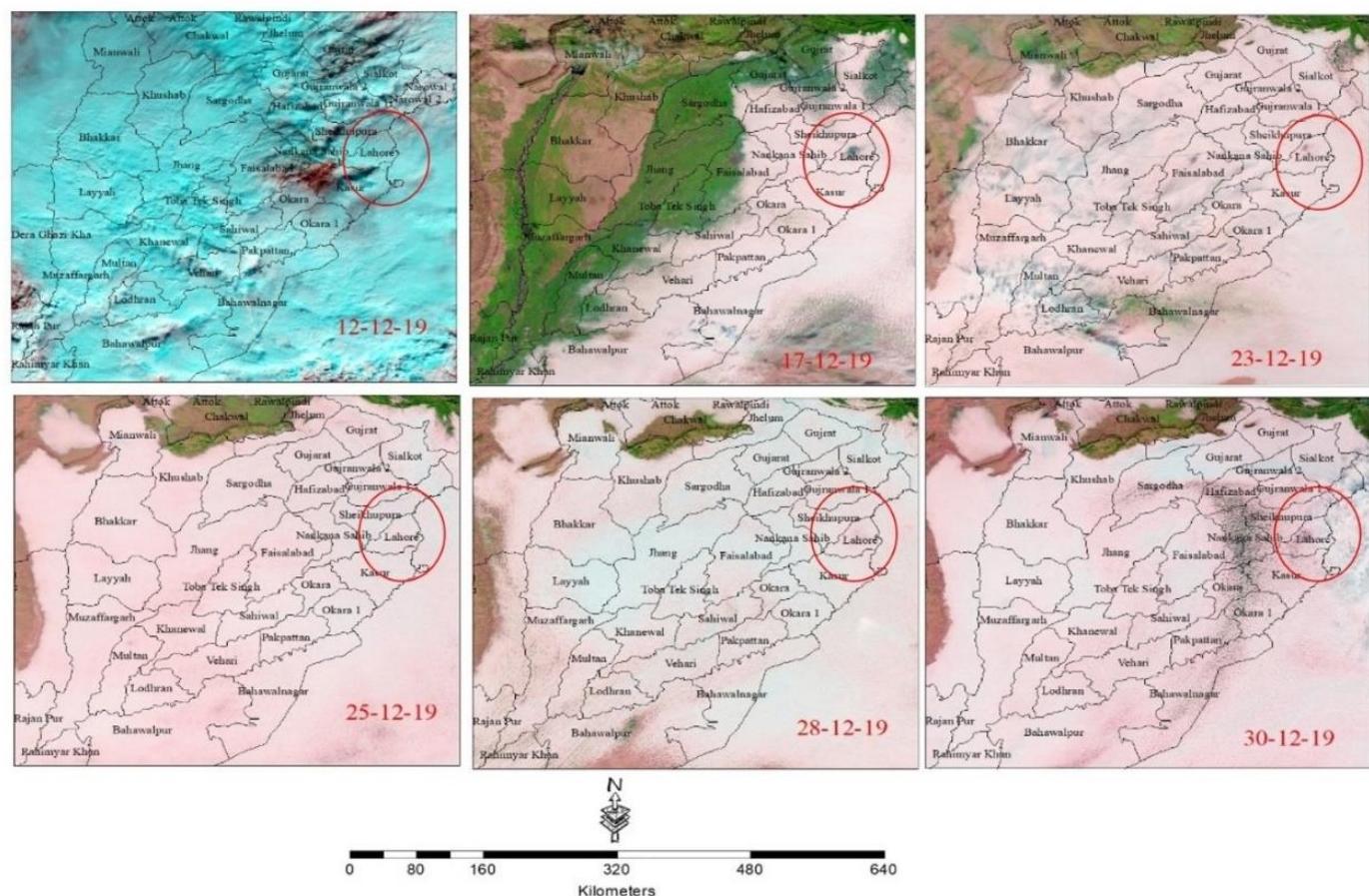


Figure 6. MODIS data showing weather conditions during December in Lahore

The residents of the northern area of the city are more prone to eye irritation and dry throat, which could lead to severe visibility and breathing issues. The molecules of nitrogen settle for longer durations, and the dispersion rate is low in the winter season, which causes a long-term effect on people's health. The environmental and atmospheric conditions deeply impact human behavior and mental health. It could cause behavioral disorders such as aggressiveness, depression, and anxiety, as shown in figure 8. Most of the people have encountered these issues living in the highest NO₂ concentrated areas. The poor air quality in Lahore has extensively affected human health conditions, as evident from the resident's experiences, environmental data, and satellite monitoring. It has been noticed that areas, where the Concentration of NO₂ was highest received more complaints regarding health issues caused by poor air quality. Therefore, the dominant areas were Gulberg Town, Samnabad, Ravi Town, and Iqbal town. About 56% of people feel eye irritation (figure 9) when exposed to the outside environment, while 40% complain about dry throat, 31% sneezing, and 19% runny nose due to poor air quality. Similarly, in this study, spatial variations show that the areas where people use more private transport and the main centers of the city face the worst situation in terms of air quality, and satellite data also show the highest level of NO₂.

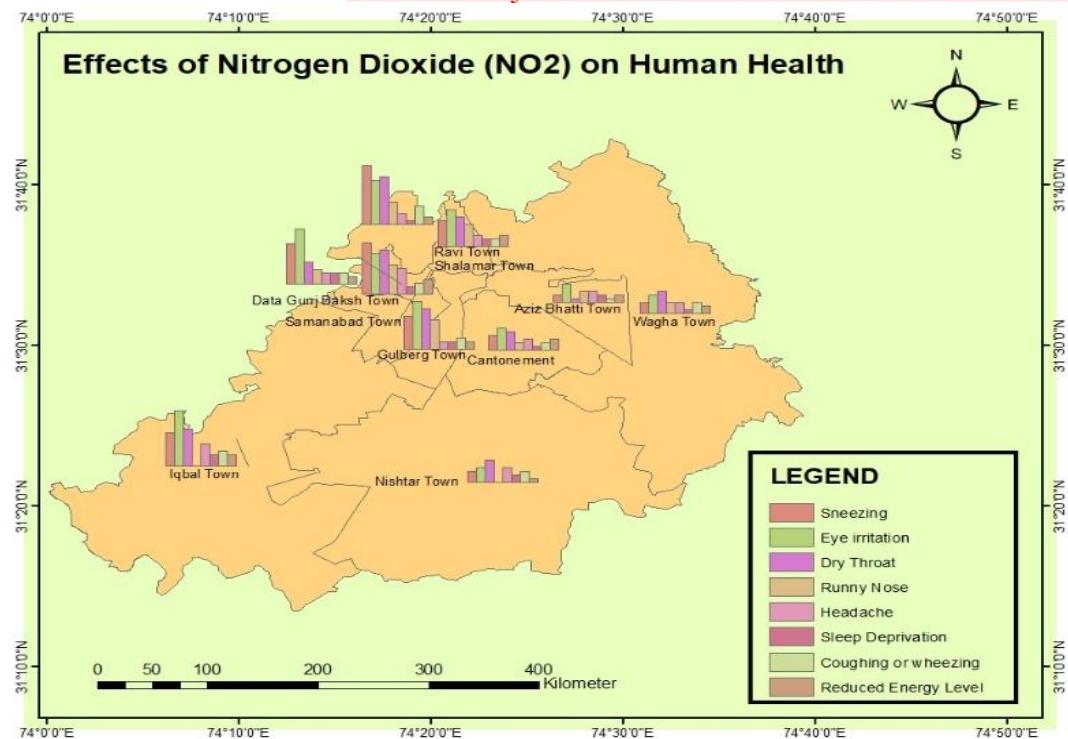


Figure 7. Map showing effects of NO₂ on Human Health

Almost 55% of people said that they use their private cars rather than use public transport for intercity movement (Figure 10). We evaluated in his study that the main contributor to the increase in NO₂ concentration is the burning of coal and vehicular emission.

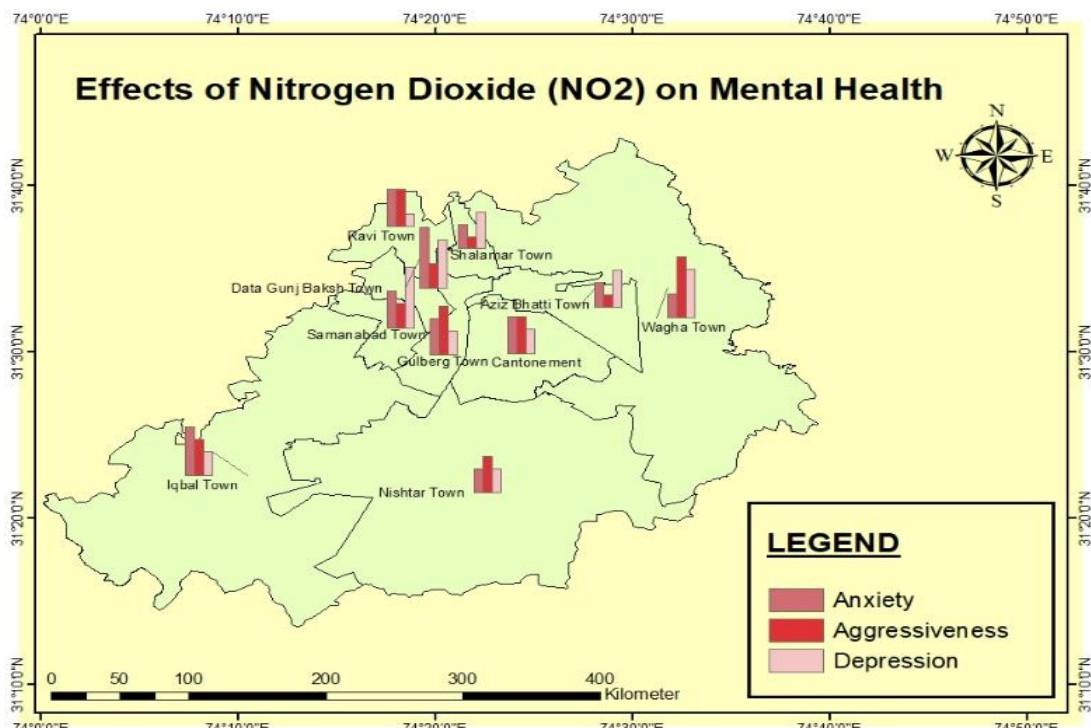


Figure 8. Effects of NO₂ on the mental helath of humans

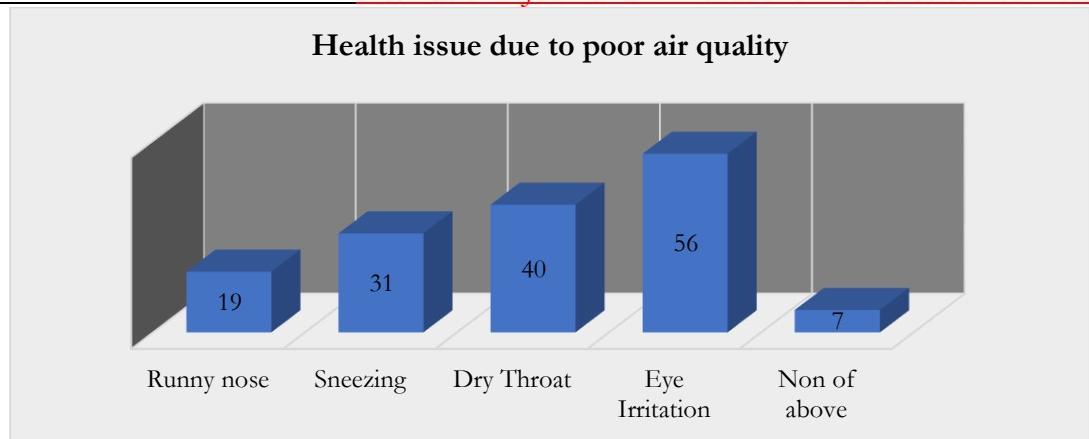


Figure 9. People's Perception of Poor Air Quality

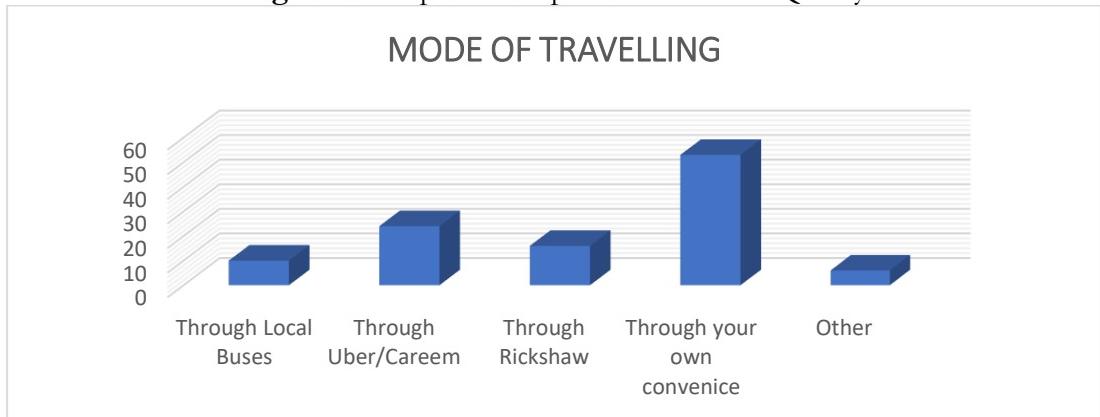


Figure 10. Modes of intercity traveling

Aerosols are tiny solid and liquid particles that float through the air. Aerosols include, but are not limited to, dust carried by the wind, sea salts, volcanic ash, smoke from wildfires, and factory pollutants. Aerosols can act as both a cooling agent and a warming agent on the surface, depending on their size, composition, and location. They can either encourage cloud development or prevent it. Some aerosols are dangerous to humans if inhaled.

Based on data collected by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite, these maps depict global monthly averages of aerosol quantities. Aerosol optical thickness is a satellite-based measurement based on the fact that aerosols alter the atmosphere's reflectance and attenuation of visible and infrared light. The sky is clear and visibility is excellent when the optical thickness is less than 0.1 (pale yellow), while it is extremely cloudy when the value is closer to 1 (reddish brown).

There are a variety of processes that can contribute to elevated aerosol levels at various times and locations. From July to September, South America is subject to heavy aerosol levels. The frequent seasonal land clearing and agricultural fires in the Amazon Basin and Cerrado regions are to blame for this trend. The central and southern regions of Africa (June–September) and Southeast Asia (March–May) share a similar seasonal trend for aerosols (January–April).

Nonetheless, fires are not always associated with high levels of aerosol concentrations. For instance, dust storms cause a significant increase in aerosol quantities in the Arabian Peninsula and the surrounding oceans from May through August every year. There are certain months when high levels of aerosols settle in in the foothills of the Himalayas

in northern India, and for the most part of the year, they hang out over eastern China. The increased levels of aerosols are the result of air pollution caused by humans. The number of molecules of NO_2 in an atmospheric column (from the Earth's surface to the top of the atmosphere) above a square centimeter of the surface is known as total column depth that vary throughout the year. The same measurement from the earth's surface up till troposphere is known as tropospheric depth.

Temporal variations in concentration of NO_2 in tropospheric and total column depth were examined as captured by AIRS sensor and mapped the trends in Figure 11 and 12.

Figure 11 and Figure 12 are showing a clear variation in NO_2 level during the era of COVID as the concentration was high before arrival of COVID that declined with respect to Total Column from 2019 until now as shown in figure 11 and 12 highlighted with red box.

Time Series, Area-Averaged of NO_2 Total Column (30% Cloud Screened) daily 0.25 deg. [OMI OMNO2d v003] molecules/cm 2 over 2010-01-01 - 2022-08-21
Region 60.3809E, 23.0438N, 78.75E, 37.37N

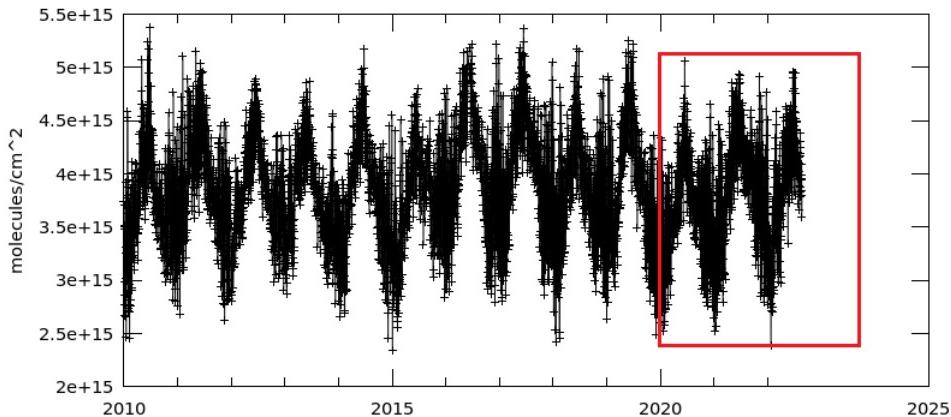


Figure 11. Temporal variations in total column depth of nitrogen dioxide from 2010 to 2022.

Time Series, Area-Averaged of NO_2 Tropospheric Column (30% Cloud Screened) daily 0.25 deg. [OMI OMNO2d v003] molecules/cm 2 over 2010-01-01 - 2022-08-21, Region 60.3809E, 23.0438N, 78.75E, 37.37N

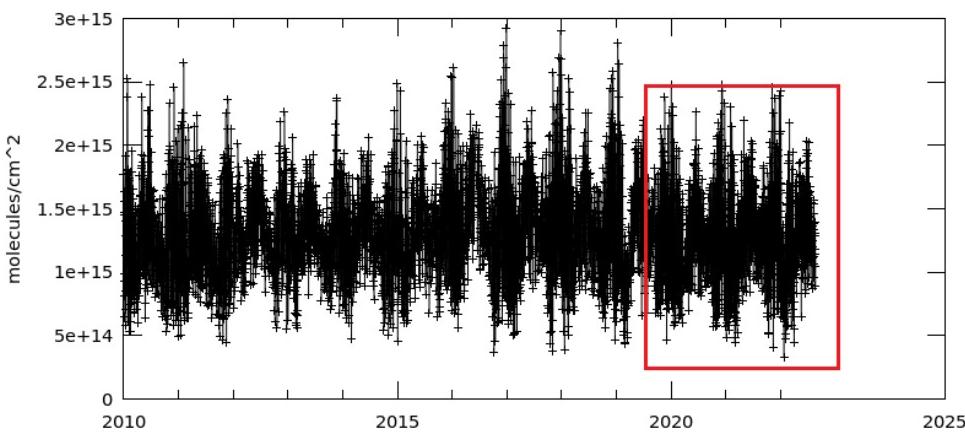


Figure 12. Temporal variations in tropospheric column depth of nitrogen dioxide from 2010 to 2022.

Conclusion

It is concluded that a reasonable difference in air quality has been noticed from the year 2010 to 2019, which declined due to the arrival of COVID. The concentration of NO_2 is gradually increasing since 2010, as in 2015, most of the areas were vulnerable to NO_2 gas. Although moderate and low concentrations are also noticed in some areas, including Nishter and Iqbal town. Most effectively, 2019 showed highly concentrated patterns of nitrogen dioxide around the city. Nitrogen dioxide has multiple patterns due to seasonal changes and can be monitored by temporal imageries. According to the satellite imageries, the

concentration of NO₂ is particularly high in winter as compared to summers in Lahore city. Similarly, the questionnaire results show that the areas with concentrations of NO₂ faced common health issues, including eye irritation, dry throat, and coughing. Therefore, the government needs to take immediate steps as the air quality of Lahore is getting worsened day by day. This study will help to understand the importance of satellite data to monitor the concentration of NO₂, along with highlighting the main areas where the levels are highest. This study will also help the concerned authorities to manage and control the air quality in the highest concentrated areas. An awareness campaign with real-time data may be useful in this regard.

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